

Food Fortification Stability Study

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OBJECTIVES

This study aimed to assess the stability of vitamin content, sensory acceptability and color variation in fortified spaceflight foods over a period of two years. Findings will help to identify optimal formulation, processing, and storage conditions to maintain stability and acceptability of commercially available fortification nutrients. Changes in food quality were monitored to indicate whether fortification affects quality over time (compared to the unfortified control), thus indicating their potential for use on long-duration missions.

METHODS

Selection of Vitamins

Previous Advanced Food Technology (AFT) research has identified five compounds (phyloquinones [vitamin K], thiamin [vitamin B1], folic acid [vitamin B9], pantothenic acid [vitamin B5] and tocopherols [vitamin E]) as candidates for the fortification blend. These compounds show significant degradation trends in the spaceflight food system and may not be adequately available on long-duration missions. Vitamin selection was based on the following criteria:

- Is vitamin concentration in the current International Space Station (ISS) diet adequate to meet Recommended Daily Intake (RDI) after two years of ambient storage?
- Has a countermeasure other than food fortification already proven stable and readily available?
- Are both water- and fat-soluble vitamins represented in the vitamin selection of the study?

Preparation of Vitamin Premixes

The above vitamins were blended into a premix (DSM, Freeport, TX), such that the final concentration per serving would be expected to equal 25% of the RDI after two years of ambient storage. Fortification nutrient stability was considered acceptable if at least 85% of the original dose remained after two years of ambient storage.

NOTE: All premixes were developed with consideration for thermal process, water activity (aw) and packaging requirements. The result was separate premixes for thermostabilized and freeze-dried foods.

Sample Preparation

Eight food products (table 1) were selected on the basis of nutritional content, processing method (freeze dried vs. retorted), food matrix and formulation, and ease of fortification.

Table 1. Fortified Space Foods	
Freeze Dried Foods	Thermostabilized Foods
Potatoes Au Gratin	Curry Sauce with Vegetables
Scrambled Eggs	Chicken Noodle Soup
Italian Vegetables	Grilled Pork Chop
Noodles and Chicken	Rice with Butter

All samples were processed according to standard ISS production specifications; each batch was sized to deliver about 180 servings of product. Two-thirds of each batch was fortified with the vitamin premix and the remaining product served as the control. Packages of fortified and control foods were placed into chambers at 4°C, 21°C, and 35°C for sensory, color, and nutritional evaluation through two years of storage.

NOTE: In an effort to preserve quality, all freeze-dried foods were placed into nitrogen-flushed metal cans (with O₂ scavengers), immediately after production (according to spaceflight specification) until they could be packaged into individual servings.

Sample Evaluation

Sensory Evaluation- Untrained panelists (n ≥ 25) evaluated samples for overall acceptability, appearance, aroma, flavor, texture, and color, using a 9-point hedonic scale after six months (35°C), one year and two years (4°C and 21°C) of storage. Samples scoring 6.0 or higher were considered acceptable (according to current space food acceptability guidelines).

Color Measurements- Color analysis was conducted at each time point (in triplicate), using the Hunter D25LT Colorimeter (HunterLab, Reston, VA) after six months (35°C), one year and two years (4°C and 21°C) of storage. Color differences were reported as ΔE_{94} values (difference between initial and 6-, 12- and 24- month L-a-b score). To optimize color evaluation, heterogeneous samples were divided into individual components and analyzed separately.

Chemical Analysis - Three packages of fortified and control foods were sent to Covance Laboratories (Madison, WI), after six months (35°C – temperature abuse scenario) one year and two years (4°C and 21°C), and analyzed for folic acid, pantothenic acid, thiamin, vitamin E (natural) and vitamin K1 content, according to AOAC official methods (Official Methods of Analysis of AOAC International ed.).

RESULTS

Sensory Analysis

The organoleptic quality of fortified space foods was maintained for up to two years at 4°C and 21°C. Italian Vegetables, Scrambled Eggs, Chicken Noodle Soup and Curry Vegetables all received unsatisfactory scores following one year of storage at 35°C.

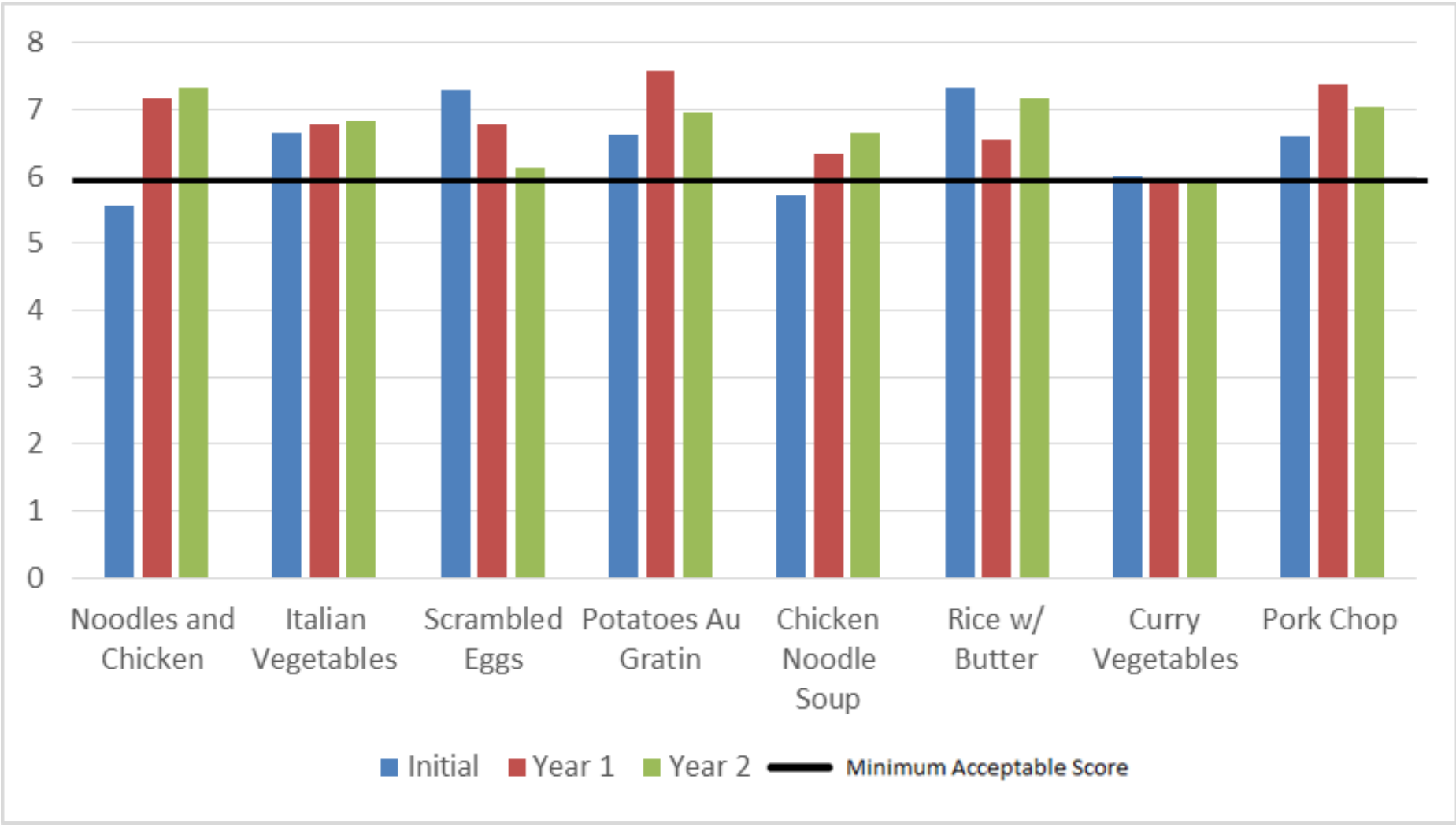


Figure 1. Overall acceptability scores of fortified space foods, following one year and two years of storage at 21°C. All items received satisfactory scores after one and two years of room-temperature storage.

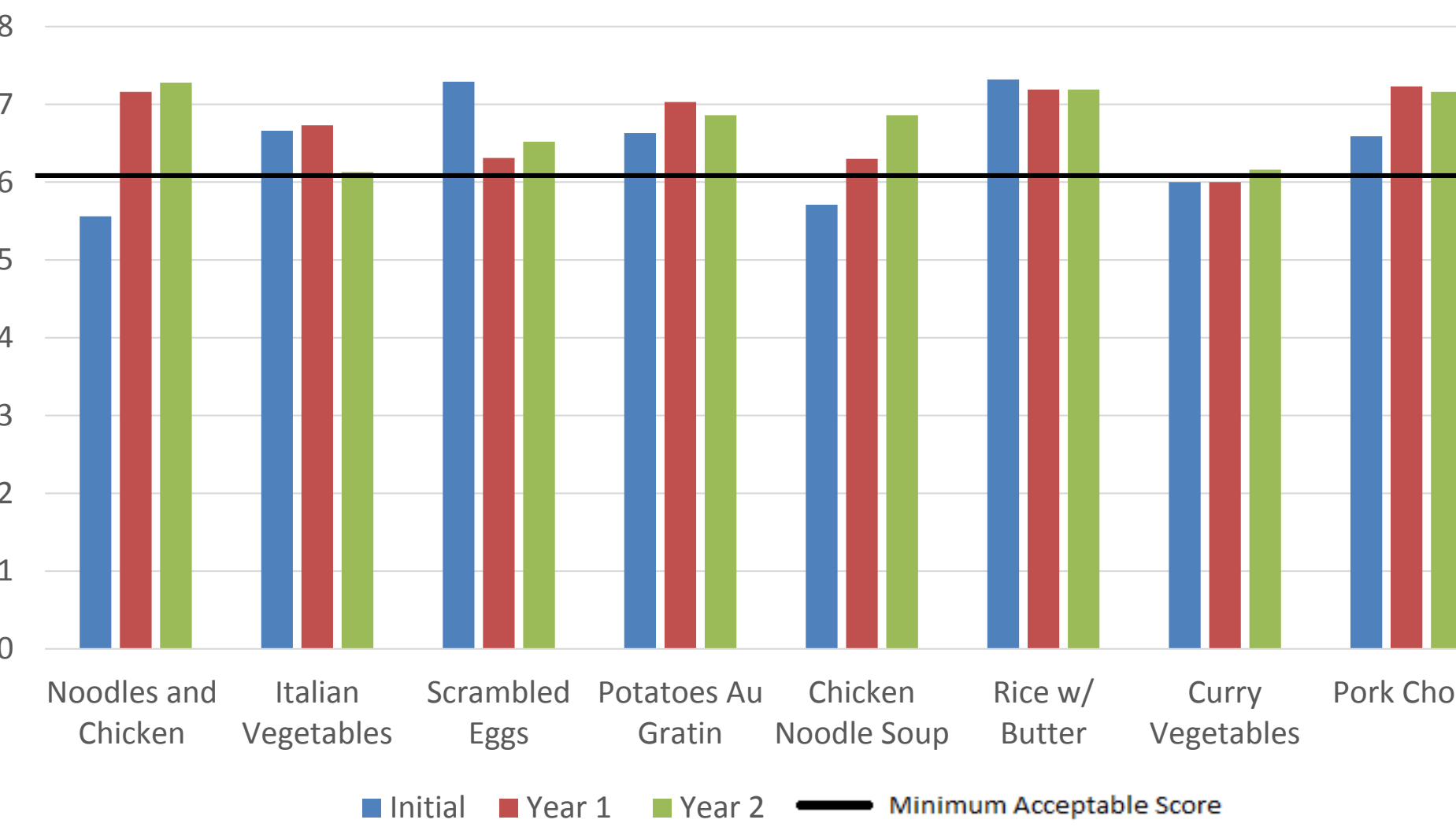


Figure 2. Overall acceptability scores of fortified space foods, following one year and two years of storage at 4°C. All items received satisfactory scores after one and two years of low-temperature storage.

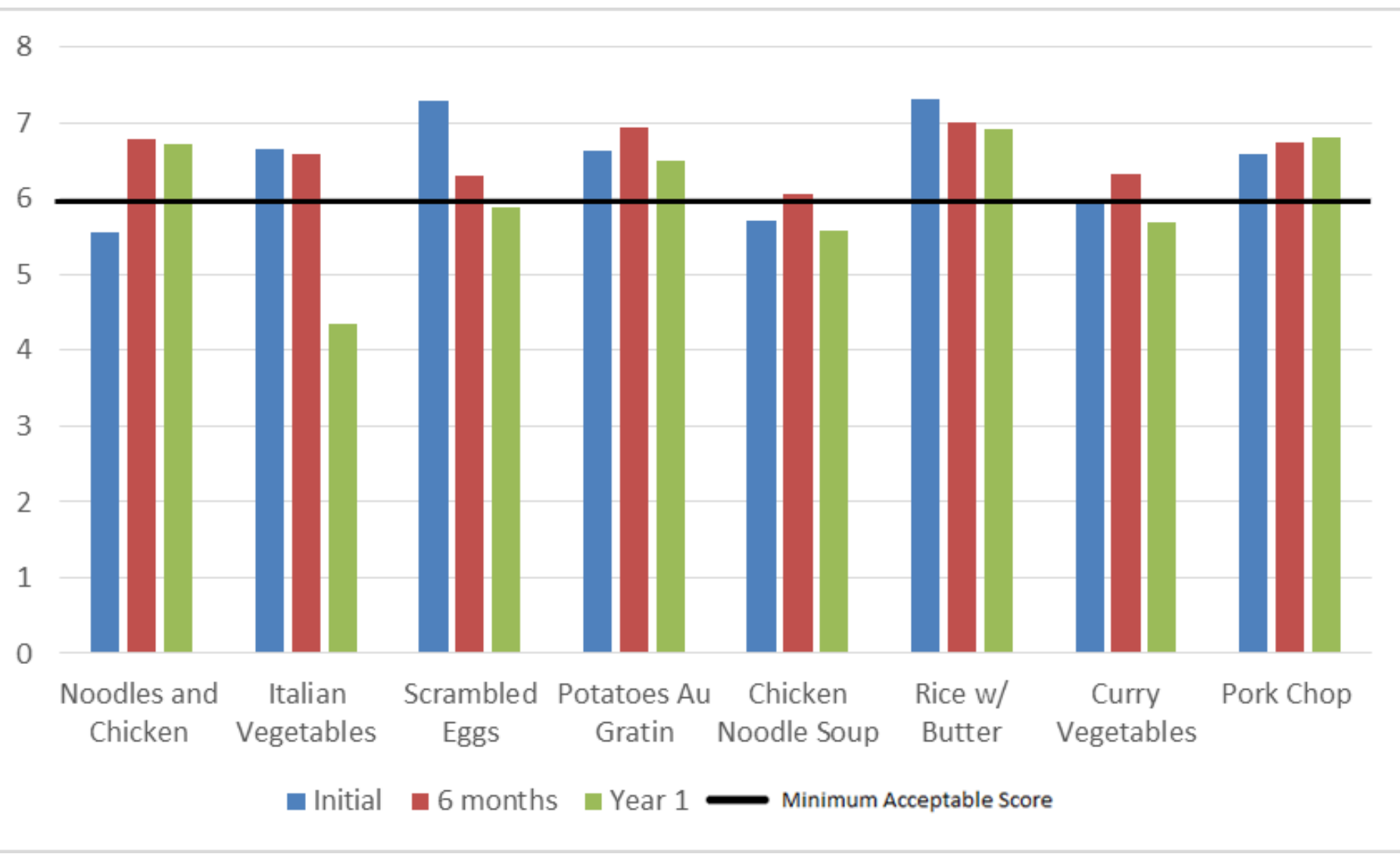


Figure 3. Overall acceptability scores of fortified space foods, following six months and one year of storage at 35°C. Italian Vegetables, Scrambled Eggs, Chicken Noodle Soup and Curry Vegetables all received unsatisfactory scores after one year of storage at 35°C

Color Analysis

The rate of color degradation was greatly abated in the presence of the vitamin premix. In most cases, the degree of color change in fortified spaceflight foods was notably lower than the control set. Temperature also increased the rate of color degradation in both control and fortified samples. However, the effects of temperature were slightly less apparent after two years of storage. In most cases, items that exceeded the threshold of visible detection at 4°C also exceeded this limit at 21°C after two years of storage, indicating that refrigeration is not necessary for preserving the color of fortified foods. .

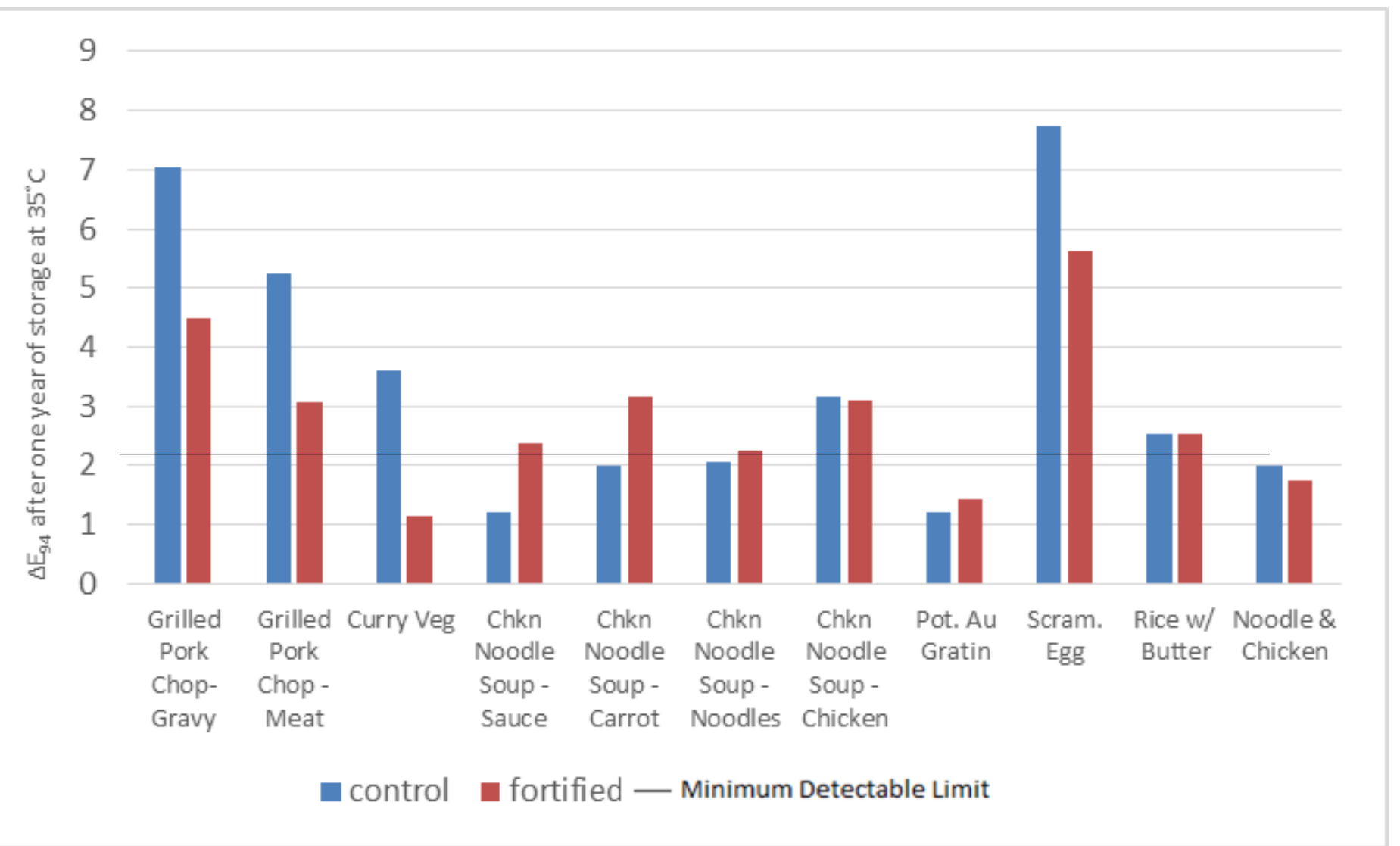


Figure 4 . Color difference between initial analysis and one year of Storage at 35°C. There were visually detectable color differences in Grilled Pork Chop, Chicken Noodle Soup, Curry Sauce with Vegetables and Scrambled Eggs after one year of storage at 35°C. In most cases, color change in fortified products was less than control products.

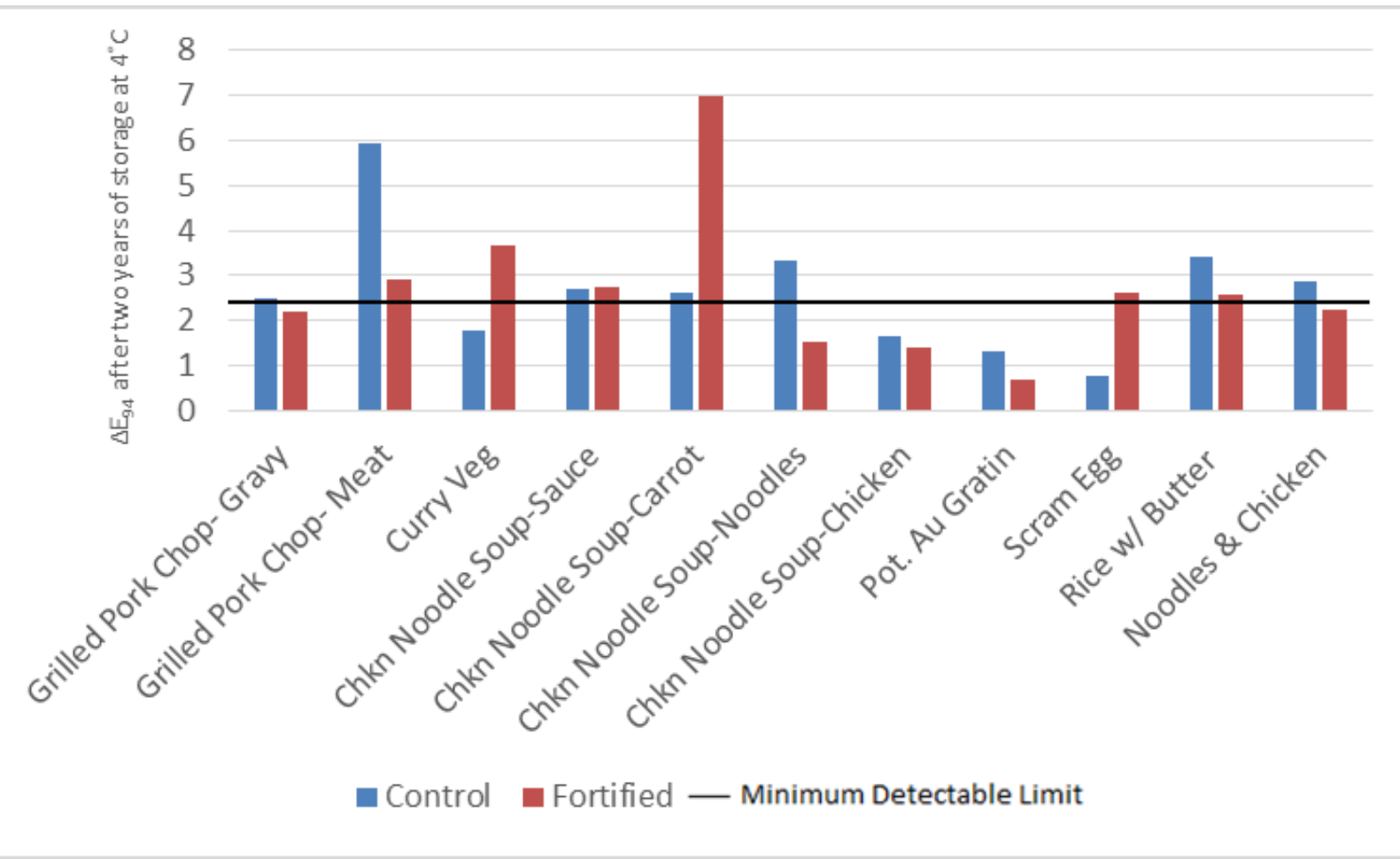


Figure 5

Figure 5. Color difference between initial analysis and two years of storage at 4°C. In most cases, ΔE_{94} values for control samples were visibly higher than fortified samples. The only exceptions were the carrot component of Chicken Noodle Soup, Scrambled Eggs, and Curry Sauce with Vegetables, all of which had high color variability in initial samples. The peak observed in fortified Scrambled Eggs is likely due to uneven browning during production.

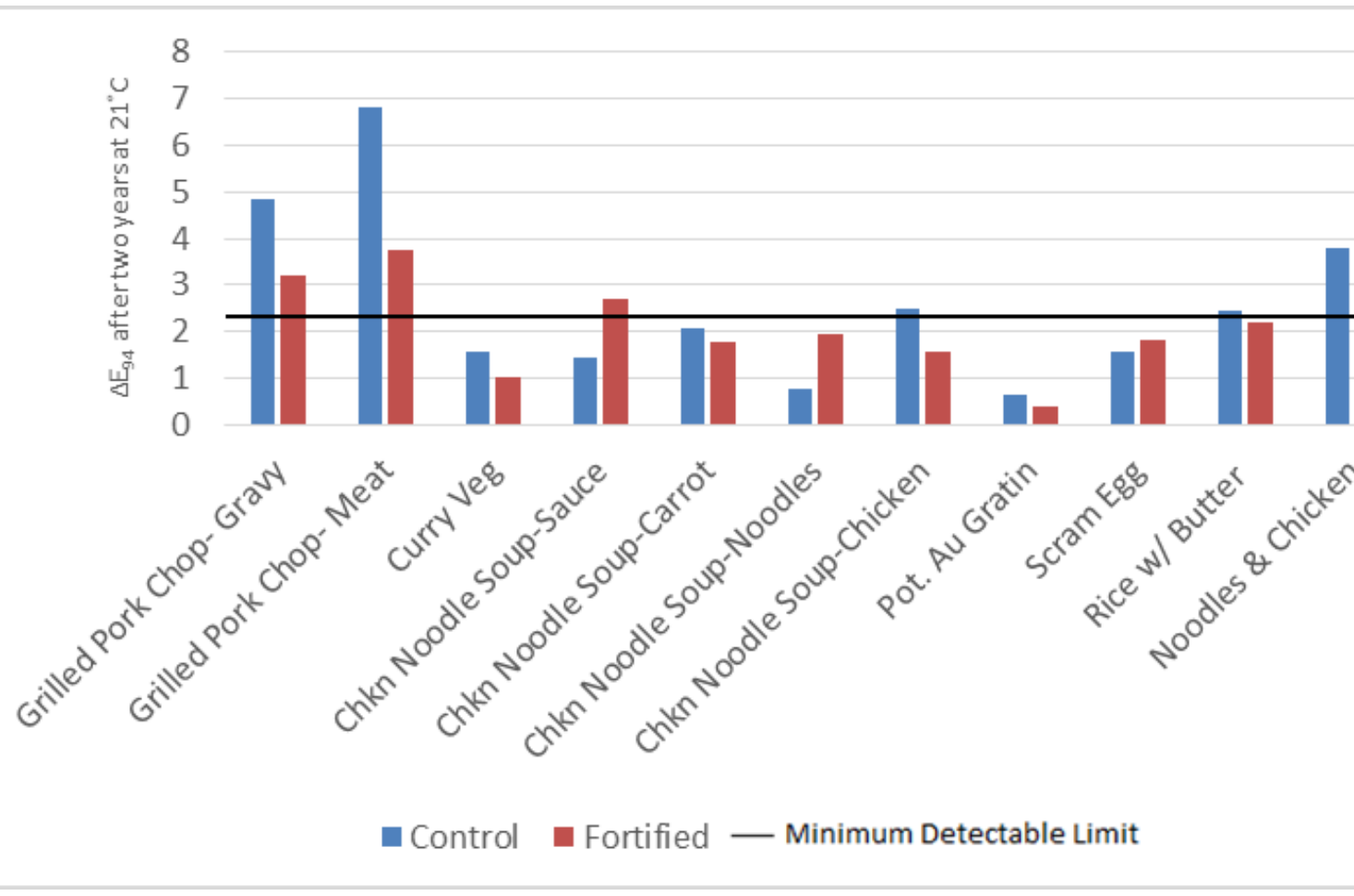


Figure 6

Figure 6. Color Difference between initial analysis and two years of storage at 21°C. In most cases, ΔE_{94} values for unfortified samples were visibly higher than fortified samples. The only exception was the fortified sauce component of Chicken Noodle Soup, which exceeded the threshold of visible detection, while the unfortified version remained below the detectable limit.

Nutrient Analysis

Vitamins were most stable when stored at 4°C. High temperature storage negatively impacted vitamin stability in most foods. Thiamin was extremely susceptible to thermal inactivation, with vitamin content degrading rapidly in thermostabilized foods that were stored at 35°C. Vitamin E was relatively resistant to thermal inactivation, with vitamin content remaining above 85% of the original added concentration in most products, regardless of storage temperature.

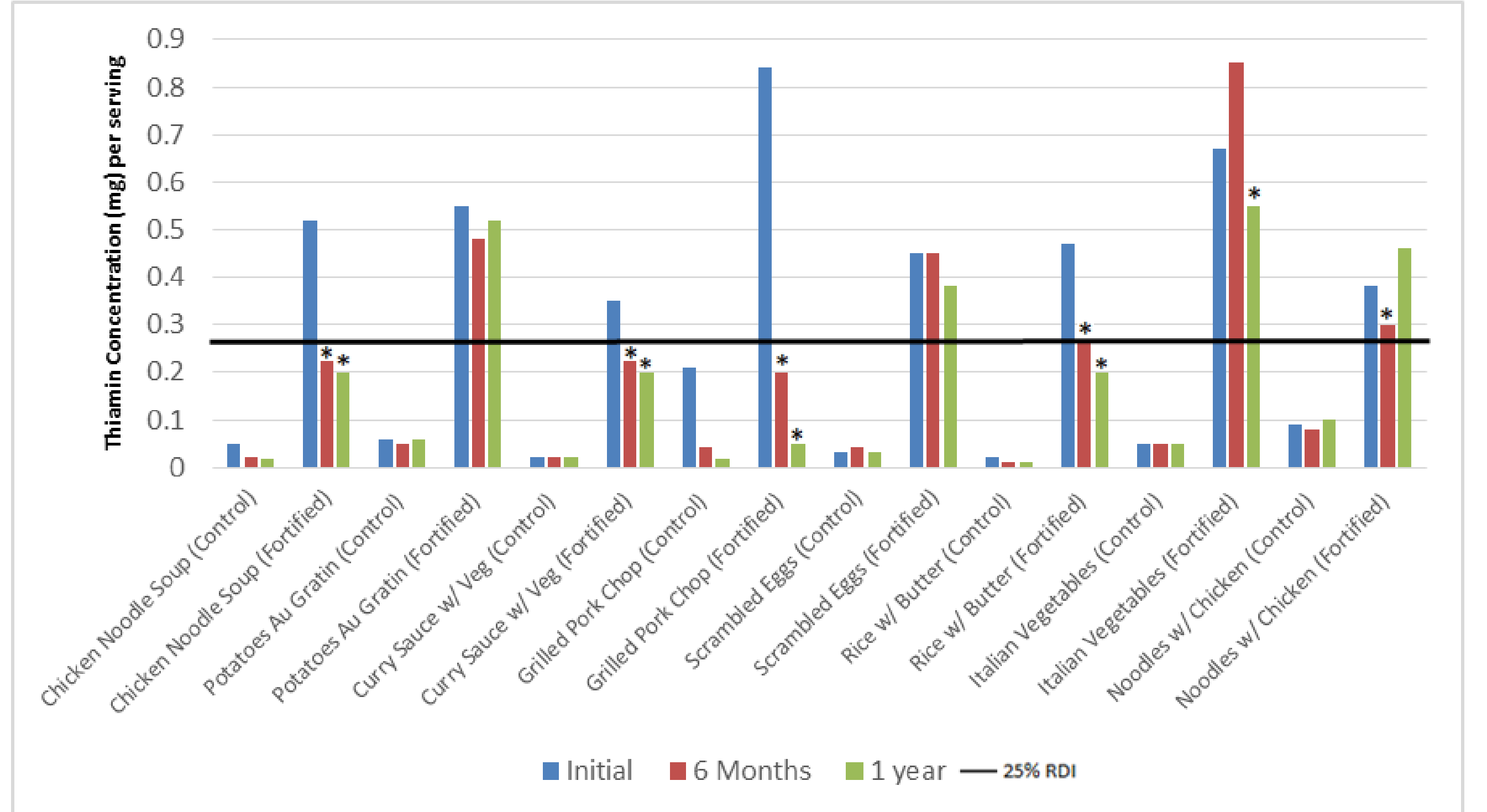


Figure 7. Concentrations of thiamin in fortified and control spaceflight foods after 6 months and 1 year of storage at 35°C. Thiamin concentrations in thermostabilized foods below 85% of the initial concentration after only 6 months of storage.

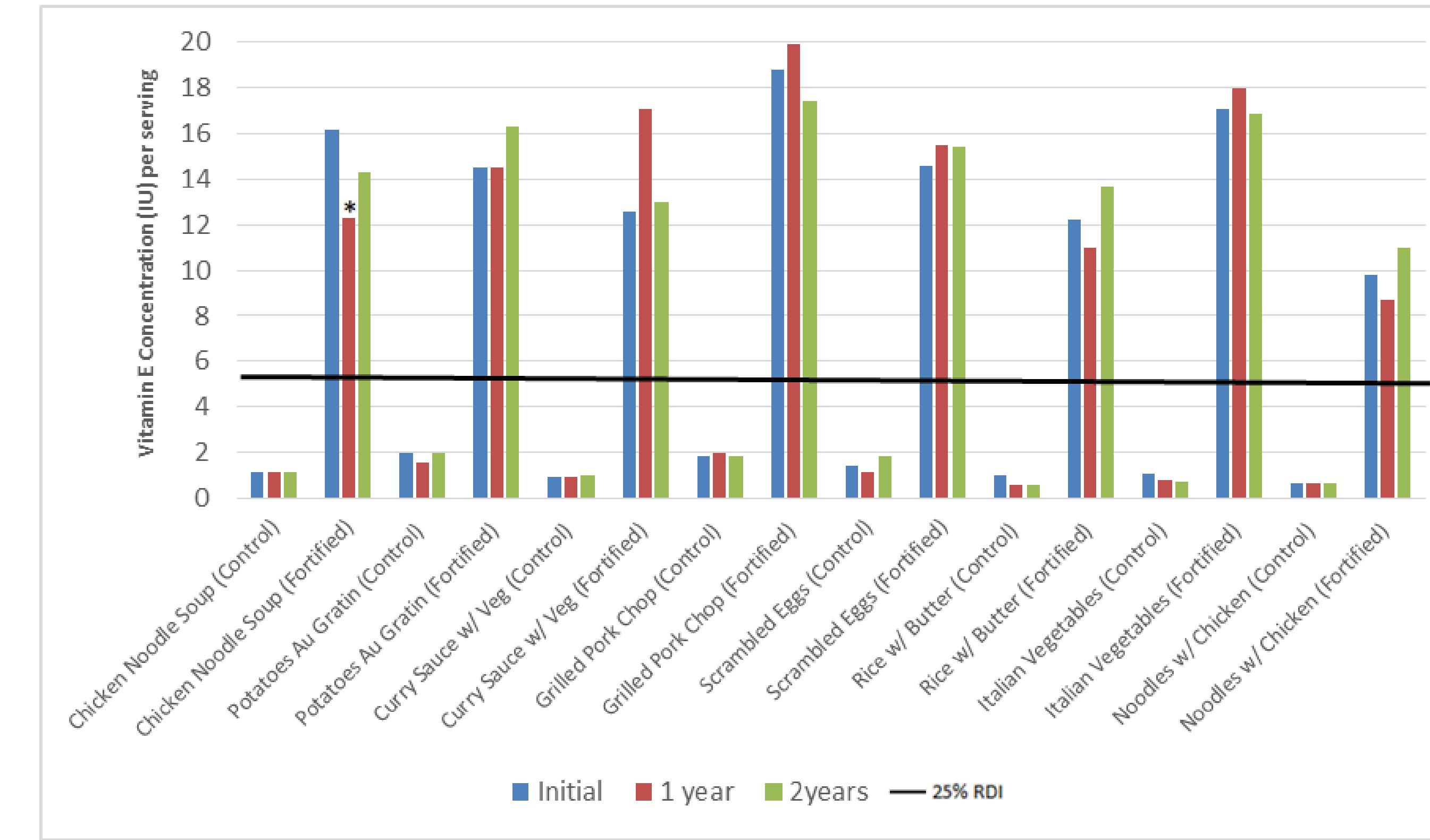


Figure 8. Concentrations of vitamin E in fortified and control spaceflight foods after 2 years of storage. Vitamin E content remained stable in most food products, even without low temperature storage.

CONCLUSIONS

- Vitamin fortification reduces the rate of color degradation in stored space foods; however, this activity is negated by high-temperature storage.
- Vitamin fortification alone does not negatively impact sensory properties of space foods. The organoleptic quality of foods is most affected by high-temperature storage.
- Storage at 35°C (temperature abuse scenario) is detrimental to most test compounds even within a few months, except for vitamin E, which was stable at all storage temperatures. Thermostabilization is detrimental to thiamin stability, when coupled with high-temperature storage. Vitamins are most stable when stored at 4°C, therefore refrigeration may prove beneficial during long-duration missions.